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The Present Status of the Evidence for the Atom-Annihilation Hypothesis

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THE purpose of this paper is to present a brief review[1] of such evidence as we have obtained in the geomagnetic studies which we have been conducting from this laboratory during the past twenty-five years for the atom-annihilation hypothesis as to the origin of cosmic rays in intergalactic space.

It was 1927 before it had become generally recognized that the cosmic rays come from beyond our atmosphere, or, as I stated at the British Association's meeting in Leeds in '27, from beyond the Milky Way. At the Como conference, held in the fall of '27, Professor Rutherford expressed to that conference, as well as to me personally, his guess that the cosmic rays originate in the outer reaches of the earth's atmosphere. I told him that I thought that view was completely negatived by our own observations, for in 1926 I had taken simultaneous readings night and day for several days high in a narrow valley in the Bolivian Andes (altitude about 15,000 feet) with two good Wolf electrometers, and found, well within the limits of observational uncertainty—estimated at not more than two or three percent—no detectable indication of a change in discharge rate when the Milky Way went completely out of sight for as much as six hours at a time. Also, in our measurements in Muir Lake (altitude about 12,000 feet) and Arrowhead Lake (altitude 5000 feet) in Southern California, we had proved in '25 and '26 that we could detect these rays through the equivalent of five atmospheres and more of water, and also could reduce depth-ionization readings to one and the same curve through the approximate assumption that weight for weight air and water had the same absorption for these rays. After that Rutherford never took the opposite side of that argument with me, so I am wont to take 1927 as marking the end of any general opposition to the view that the cosmic rays originate somehow in interstellar space, or at least come to us essentially uniformly, i.e., with random distribution, from all portions of the celestial dome.

Further, the absence found by all observers of any appreciable day and night difference in cosmic-ray discharge rates, save for minute secondary influences caused by the heating and cooling of the atmosphere, obviously eliminated the sun and presumably also the stars as the source of cosmic rays. For on account of the closeness of the sun to us and the enormous distance of the stars, if cosmic rays were produced in and emitted by such hot bodies, the inverse square law of intensities with distance would require that the ratio of solar to stellar cosmic rays reaching the earth have the same stupendous value as the ratio of sunlight-and-heat to starlight-and-heat. The only observer, so far as I know, who ever claimed to find cosmic rays coming from any particular star was Kolhörster, who in that same year (1927) at the meeting of the British Association at Leeds not only expressed himself publicly against the assumption of the uniformity of distribution of the rays over

[1] A much more complete discussion of the problem up to the year 1947 is given in *Electrons (+ and −), Protons, Photons, Neutrons, Mesotrons and Cosmic Rays* (University of Chicago Press, Chicago, 1947).

the celestial dome, but in private conversation with me told me that he had found a 15 percent increase in discharge rate of his electroscope when the rays from a particular star fell upon it. I think this claim was shortly afterward withdrawn. This merely shows how long it took for us experimenters in this field to get into agreement about the fact of this random distribution. This fact is, of course, vital as to the place and type of origin of cosmic rays. Today, so far as I know, nothing has happened to change my conclusions of 1927, as stated at Leeds.

Further, in 1928 Jeans says in Nature[2] "The falling of electrons into protons is practically the certain source of the sun's heat." This view of the complete annihilation of the mass of the atom (in terms of the then current ideas as to the electromagnetic origin of mass) and its transformation into radiant energy through the collapse of its electronic shell was vigorously maintained by both Jeans and Eddington throughout the twenties. This fact was responsible for one of my own false leads. For certainly the simplest and by all odds the most likely explanation of the foregoing uniformity of distribution of cosmic rays was that atomic transformations of some kind taking place in atoms dispersed through space constituted the origin of these rays. There were only two kinds of transformations possible which could yield large energy radiations. The one was the building up of the heavier elements out of hydrogen (energies being computed from packing fractions); the other, atom-annihilation, which should yield about a hundred times more energetic rays. Since it was certain, as I thought from our work, that the cosmic rays did not originate in the sun or stars, if Eddington and Jeans were right, and I greatly respected their reputations, then the only known atomic transformation possible was the building up of the common atoms out of hydrogen assumed to be going on occasionally in interstellar space. I tried for a year or so with the aid of speculations of this sort, using the so-called Klein-Nishina absorption

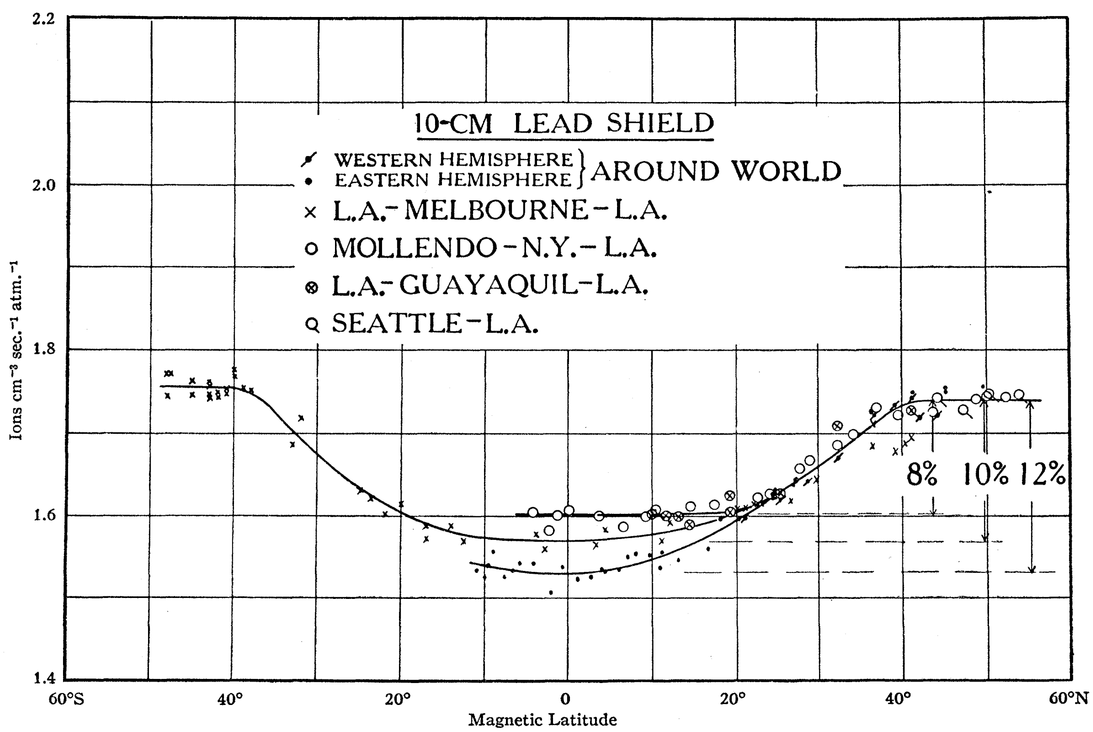

FIG. 1. Sensitive electroscopes taken on repeated voyages off the west coast of South America show a plateau of unchanging cosmic-ray intensities between Mag. Lat.'s 0° and 20° N (see upper horizontal line). This plateau does not appear when the magnetic equator is crossed in the neighborhood of Singapore. (See lowest line in the figure.)

[2] Jeans, Nature 121, 467 (1928).

formula to make comparisons with our observed cosmic-ray absorption in water, but in 1929, having become skeptical, in spite of my theoretical colleagues, about the validity of the Klein-Nishina formula for the purpose of computing cosmic-ray energies, I called in Carl Anderson and asked if he would like to join me in trying to build a vertical cloud chamber,—only horizontal ones had thus far been used—and with it attempt to make a *direct* cloud-chamber measurement of the energy of cosmic-ray tracks. The specifications were that we needed to measure particle-energies of not less than three billion electron volts, for if we did not get up into the range of atom-annihilation energies, which I computed for carbon as about 6 billion electron volts, we could not make the differentiation between what I thought the only two possible kinds of atomic transformations which might be the origin of the cosmic rays. The portable, high energy magnet which resulted from decisions made in these conversations, took two years in the building. It has been responsible for a large part of the results that have been obtained here in this field in the seventeen years since the summer of '31 when it first got into action. The discovery by Anderson with its aid of the positron came within a year (1932). *The very first photographs taken with this first device ever built capable of measuring particle energies of a billion electron volts and more showed that the energies of these cosmic-ray particles were far above anything that could possibly be computed from packing fraction energies*, i.e., *from the building-up process of any existing elements out of hydrogen.* For with this measuring outfit we were soon actually finding three billion volt tracks in our chamber and estimating that some of our observed particles must have energies of six billion electron volts or more. *This was definite and final proof* that our observed cosmic rays were not due to any *atom building* process. But since we had directly proved to our satisfaction from our electroscopic measurements that the cosmic rays do not come from the sun or stars anyway, it was now certain that if their origin had to do with atomic transformations at all *these had to be atom-annihilation processes in order to get into the range of our observed energies.*

Again, these direct energy measurements, taken in connection with the electroscopic evidence that the cosmic rays do not come from the stars, left nothing but atom-building or packing-fraction energy as the only remaining source of the sun's heat—a view now so ably championed, from considerations of a wholly different sort, by Bethe and also generally accepted by physicists.

Nor is this the first time that an atomic transformation has been suggested which can take place in interstellar space but is not found taking place on earth or in the stars. Bowen's spectacular solution of the century-old riddle of the nebulium lines consisted in proving that these are only so-called "forbidden lines" of very common elements corresponding to electronic jumps which will take place in interstellar space but do not take place on earth or in the stars nor presumably anywhere else where the atoms are under incessant bombardment from their neighbors. In other words, the electronic jump is here assumed to be governed by a probability function of long duration which permits the jump *in the absence of incessant collisions with neighboring atoms* and, when such collisions are eliminated for *a long enough time*, does occasionally occur.

Meanwhile, Cameron, Neher, and I had been

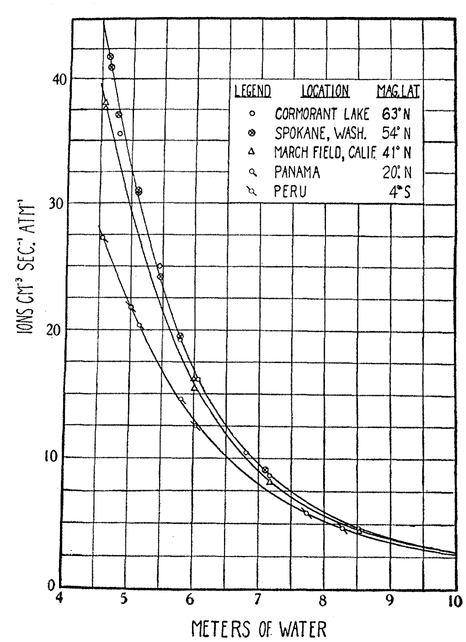

FIG. 2. The lowest curve is drawn through a series of cosmic-ray electroscope discharge rates, part of which are marked as taken in a flight at Panama (Mag. Lat. 20 N) and part as taken in a flight made near the magnetic equator in Peru. This shows that the sea-level cosmic-ray plateau found in Fig. 1 holds at all altitudes up to 22,000 feet, even when the receiver is an electroscope.

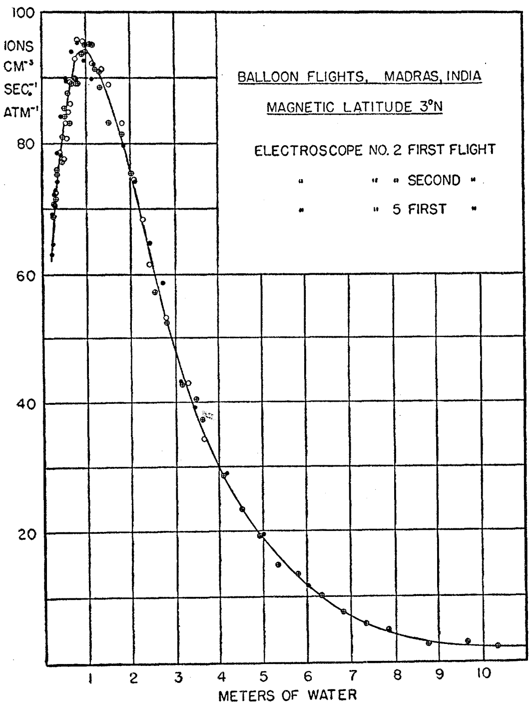

FIG. 3. Ionization as a function of depth, in equivalent meters of water, below the top of the atmosphere at Madras, India, Mag. Lat. 3° N. The total area underneath the curve is a measure of the total cosmic-ray energy coming into the earth per sq. cm in the neighborhood of Madras.

taking improved and highly sensitive electroscopes on trips all over the world beginning in 1926, the year in which Cameron and I made our first sea voyage to Mollendo and up into the Bolivian Andes. This first sea-level trip was made expressly for the sake of finding whether the earth's magnetic field reduces the rates of discharge of electroscopes as one goes south over the equator. We took along three electroscopes and made continuous observations day and night throughout the whole voyage, and reported no change in the rate of discharge "larger than the limits of our experimental uncertainties" (listed as 6 percent) throughout the whole voyage, which was reported as between Los Angeles and Mollendo, Peru. But on account of changing the position of our electroscopes from our state room to the wireless room the second day out, our series of readings did not actually begin until we were over five hundred miles south of Los Angeles. It was just because we failed to get the readings in the first few hundred miles south of Los Angeles Harbor that we drew an incorrect conclusion from these sea-level readings on this first trip. This voyage, as will presently appear, has an immediate and an important bearing on the present evidence for the atomic-annihilation theory of cosmic rays, for the horizontal line from 0° to 20° shown in the upper line of Fig. 1 and labeled "Mollendo–N. Y.–Los Angeles," also "Los Angeles–Guayaquil," seems to reveal a long cosmic-ray plateau. This plateau is not found on the opposite side of the earth (see lowest line of Fig. 1), a fact having significance, as will presently appear, for the atom-annihilation hypothesis (see below).

Our first conclusion from these sea-level readings was that the incoming rays were mainly photons and therefore uninfluenced by the earth's magnetic field. This *incorrect* conclusion was not rectified by me until the fall of 1932, when the same sea trip from Los Angeles to Mollendo and back to New York was made with one of Dr. Neher's new sensitive recording electroscopes and an equatorial dip of 7 percent ± 1 percent in the cosmic-ray intensity found be-

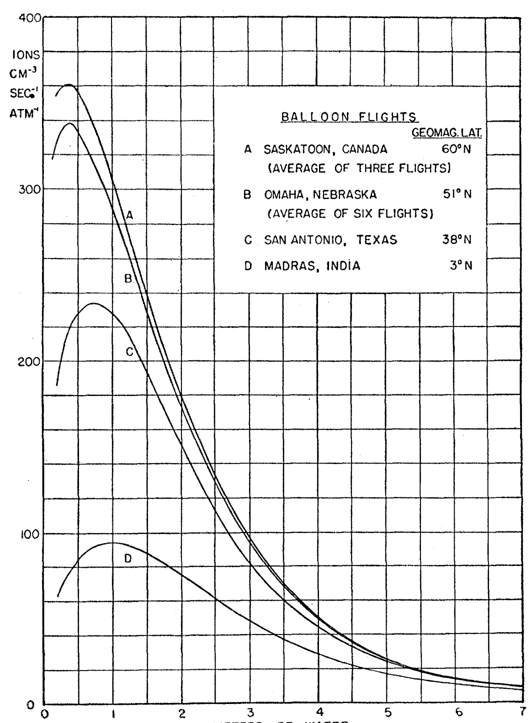

FIG. 4. The differences in the areas underneath the successive curves A, B, C, D represent the energies coming in between the corresponding latitude limits. These energies are the blocks 1, 2, 3, 4 of Fig. 5.

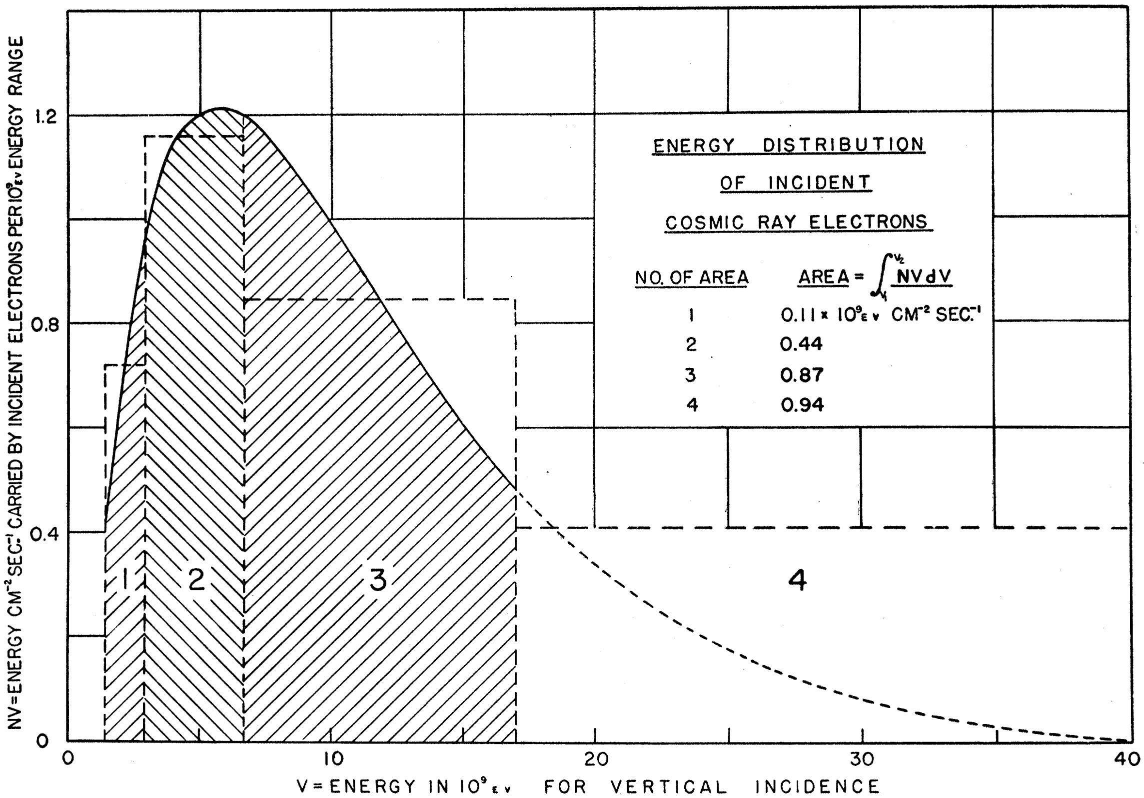

FIG. 5. The rectangular area 4 is made proportional to the total cosmic-ray energy that enters the earth at the equator. It is, in fact, the area underneath a complete cosmic-ray curve taken up to the top of the atmosphere at Madras (see Fig. 3). It is the sum of the energies of all non-field sensitive cosmic rays, no matter whether this non-field sensitiveness arises from the fact that incoming charged particles have too high an energy to be blocked off by the earth's magnetic field or whether some of the incoming rays consist of photons or neutrons which cannot because of their nature (no matter what the energies) be affected by a magnetic field. *Rectangle 4 then represents the total cosmic-ray background that is uniform all over the earth's surface.* The sum of the rectangular areas 1, 2, 3 represent the total energy of the field-sensitive cosmic rays. This sum is actually 66 percent of the total incoming cosmic-ray energy.

tween Mollendo and either Los Angeles or New York. In spite of the differences in the percent of equatorial drop found by different observers in making these sea-level surveys, all careful observers within the next ten years came into complete agreement within the limits of observational uncertainty (about 1 percent) as to the value of this equatorial sea-level drop between the latitude of Los Angeles and that of Mollendo.

All the geomagnetic surveys made by us or others up to 1932 had been made either on the sea or terra firma, sometimes on mountains. It was in 1932 that we first got the Neher recording electroscope into shape to make a geomagnetic airplane survey of cosmic-ray intensities up to altitudes of 22,000 feet. In the fall of that year Neher and I arranged to make flights as far north as magnetic latitude 63° N and in returning took continuous *sea-level* readings from Seattle to Los Angeles and then sent Dr. Neher with his electroscope from Los Angeles to Mollendo, after arranging with General Foulois of the U. S. Air Corps to take up Neher's recording electroscope for flights in airplanes both at Panama and near Mollendo after having made similar flights at Spokane, Cormorant Lake, Canada, and March Field, near Riverside, California. The results of these flights (see Fig. 2) have an important bearing on the evidence for atomic annihilation. That evidence is provided by the fact that as shown by Cameron and myself in '26 and by these sea-level trips to and from Mollendo in '32, as well as by the airplane flights in '32 at Panama and Mollendo, there came to light a perfectly flat plateau of cosmic-ray intensities between the magnetic equator at Mollendo and at Panama (Mag. Lat. 20° N) which is equally flat whether measured at sea level or at any altitude up to 22,000 feet. I shall presently use this result as quite significant evidence for the atom-annihilation hypothesis.

In '36 Neher and I first succeeded in making in both San Antonio, Texas and Madras, India, balloon flights with Neher recording electroscopes which enabled us to obtain the total incoming energy, thus: The integral of each flight, reaching in some cases up to within $1\frac{1}{2}$ percent of the top of the atmosphere, gave the total cosmic-ray energy coming into the atmosphere at the latitude corresponding to the location of the flight quite independently of whether the ionization was caused by vertical incoming rays or by rays coming in at any angle between the vertical and the horizontal. In other words, the area under the flight curve (see Fig. 3) is a measure of the total cosmic-ray energy falling on a particular square centimeter of the earth's surface at the location in which the flight is made, the only assumption underlying this statement being that this total incoming energy finally expends itself wholly in

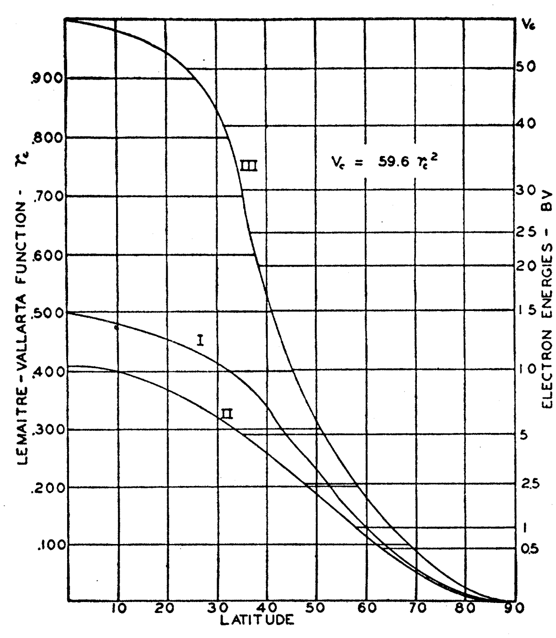

FIG. 6. The Lemaitre-Vallarta function, r_c, for three directions of incoming rays plotted against latitude. Curve I is for the vertical direction, with which the analysis in the text is mainly concerned, Curve II is for the western horizon, and Curve III is for the eastern horizon. Electron *energies* are given along the right margin (Lemaitre and Vallarta).

atmospheric ionization. The total area under the curve taken at the equator gives the total portion of the incoming energy that is *non-field sensitive*, while the difference between the area of this curve and that of a similar curve taken in the far north, for example at Saskatoon, Canada, gives the *field sensitive* portion of the incoming energy. The fact that it is field sensitive means, of course, that this portion of the incoming energy is made up exclusively of incoming charged particles, i.e., of electrons or protons, not at all of photons. In the years '36 and '37 Neher and I took a series of four such curves at four magnetic latitudes (see Fig. 4) between the magnetic equator and Saskatoon (Mag. Lat. 60°). All of these results are graphed and summarized in Fig. 5. The energy in the field-sensitive part of the incoming rays is given in Fig. 5 as of numerical value 11+44+87, the non-field sensitive as of value 94, and (11+44+87) ÷94=66 percent. This shows definitely that *66 percent of the cosmic-ray energy that comes to earth from the cosmos is electronic or protonic*, rather than photonic. In 1940 this whole series of electroscope flights was repeated. The Bangalore flight of '40 was indistinguishable from the Madras flight of '36—they have the same latitude (see lower curve of Fig. 8), and the same was true of the '36 and '40 flights at San Antonio. The Omaha and Bismark curves were somewhat displaced, as discussed in *The Physical Review*,[3] but the percentage of field sensitive energies came out 65 percent, practically identical with its 1937 value.

There is no way to distinguish so far between how much of the 35 percent (see area 4, Fig. 5) that is left is due to photons and how much to incoming charged particles of such huge energies that though charged they plunge right through the earth's magnetic field without being sensibly deflected by it. It is possible, and I now think probable, that the great bulk of even this 35 percent of the incoming energy is carried by such high energy charged particles. The foregoing percentages are a very important, and perhaps

[3] R. A. Millikan, H. V. Neher, and W. H. Pickering, Phys. Rev. **66**, 295–302 (1944). As discussed in this reference and more fully in Phys. Rev. **72**, 512 and 513 (1947), so far as the atom-annihilation hypothesis is concerned the results of all of our measurements would be the same, whether the incoming primaries are protons or electrons, since at the energies here involved, all two Bev or more, the action of the earth's magnetic field upon them would be the same within the limits of accuracy of our measurements.

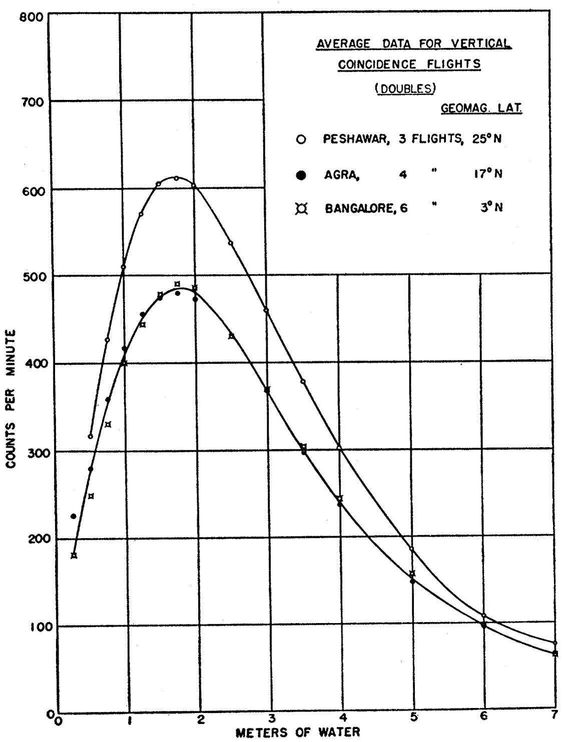

FIG. 7. Summary of vertical-counter data. Note that here, as predicted, *there is no detectable increase whatever in intensity between Bangalore and Agra as measured by double vertical-counter indicators*, but note also that in going north only the 7°.7 between Agra and Peshawar, a 21 percent increase has suddenly appeared, thus bringing to light (1) the predicted flat plateau of constant cosmic-ray intensity between the magnetic equator and Agra *for vertically incoming rays* and (2) the entrance of what we have called the strong silicon-annihilation band between Agra and Peshawar. *Note maximum at 610 ions.*

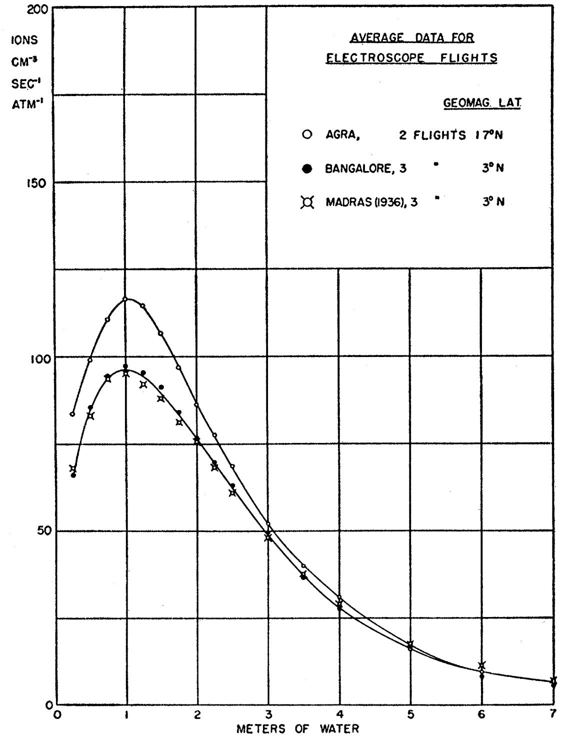

FIG. 8. Average data for electroscope flights at magnetic latitude 17°.3 N and 3° N. Note that, though the two sets of points on the Madras-Bangalore curve, both at 3° Mag. Lat., correspond to observations taken more than three years apart, one single curve fits perfectly both series of observations. This speaks well both for the reliability of the observations and for the reproducibility of the conditions. The area under the Agra curve is here 8 percent higher than the area under the Bangalore-Madras curve, in agreement with our predictions from Fig. 6 for electroscope readings.

the most important, result of geomagnetic surveys *with electroscopes*.

It is to be noted that Fig. 5 indicates that the major part of the cosmic-ray energy that comes to earth lies in the energy range between, say, 3 Bev and 17 Bev, the maximum of the incoming energy coming somewhere in area 3 of Fig. 5, or between 5 Bev and 10 Bev.

But a third important result that could be obtained from electroscope flights to the top of the atmosphere also has a very significant bearing upon the atom-annihilation hypothesis, for Bowen has determined by spectroscopic observations of the heavens the relative abundance of the atoms in interstellar space, and according to his measurements hydrogen is, as is to be expected, enormously more abundant in interstellar space than any other atom, since the universe is still supposed to be 90 percent hydrogen. The next most abundant atom in interstellar space is, as is also to be expected, helium, whose abundance is probably considerably less than one-tenth that of hydrogen. Then follow four elements of roughly equal abundance, namely, carbon, nitrogen, oxygen, and silicon. There are no other individual elements that have more than a tenth of the abundance of each of these four, and very few have even a hundredth of such abundance. This is great good fortune for the testing of the atomic annihilation hypothesis, for it means that a major part of all of the ionization produced in our atmosphere by cosmic rays is produced, according to this hypothesis, by the annihilation somewhere out in space of these five elements,—hydrogen, helium, carbon, nitrogen, oxygen, and silicon. Further, since according to Newton's second law in the case of the annihilation of each atom the transformed energy is, in general, projected

TABLE I. Critical magnetic latitudes in North America for entry of cosmic-annihilation rays.

Atom	Energy (Bev)	First entry on western horizon	Latitude of Full entry on eastern horizon	Vertical entry
He	1.9	50°	59°	54°
C	5.6	32°	49°	42°
N	6.5	27°	48°	39°
O	7.5	22°	46°	33°

through space in the form of a pair of electrons or of protons or of photons, it becomes at once possible to know what is the energy of the resulting cosmic rays that enter the earth as a result of that annihilation process. This energy thus computed is expressed in billions of electron volts in Table I.

Knowing as we do, from LeMaitre-Vallarta's famous analysis (Fig. 6), the energy of such a particle which has just enough energy to break through the resistance of the earth's magnetic field at a particular latitude and reach the earth, we can explore the surface of the earth to see whether cosmic rays of just that energy enter the earth at the appropriate latitude. For example, the energy required for an electron to shoot through the resistance of the earth's magnetic field and reach the surface vertically at the magnetic equator in India, according to reasonably reliable estimates of Neher and myself based upon Vallarta's curve, is 17 billion electron volts. The corresponding energy required to break through the earth's magnetic field at the magnetic equator in Peru is only 13 billion electron volts, and that because the earth's magnetic field in India is considerably stronger than the earth's magnetic field in Peru. The energy of the incoming electron or photon created by the annihilation of the silicon atom is, according to our computation, 13.2 billion electron volts. Therefore, we argued that, if we went to India and made vertical counter measurements of the

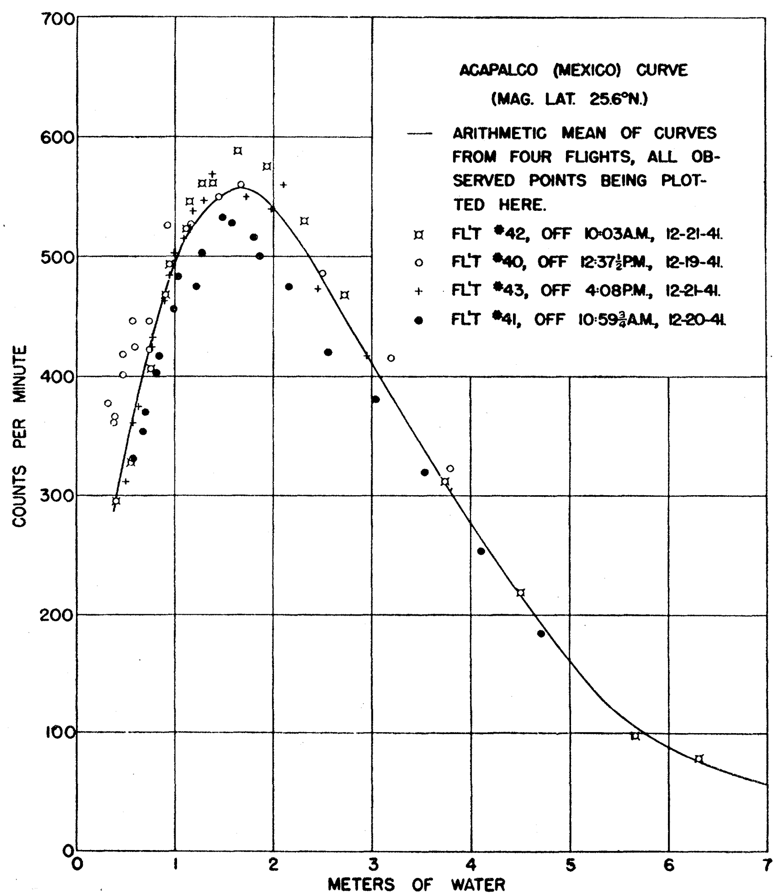

FIG. 9. Every individual observation taken in all four of the Acapulco flights is recorded in Fig. 9. The best obtainable smooth curve is drawn for each of the four flights. The final full curve shown is the arithmetic mean of these four curves. *Here maximum is at 560 ions.* In general, in all these curves each recorded point is the actual counting rate in a 4-minute interval in that flight at the recorded mean pressure in that interval.

cosmic-ray energy coming in at the equator, no annihilation silicon rays could be found there because they could not get down to earth through the blocking effect of the earth's field. But we computed that, if we went about 20° farther north, where the earth's magnetic field was weak enough to let these silicon rays through, we ought to find, in going north from the magnetic equator, the incoming cosmic rays not increasing at all in intensity until we reached about the latitude at 20° magnetic north, where a group of new rays should be revealed as just beginning to come in vertically. In other words, making measurements of the total vertical incoming cosmic-ray energy at Bangalore, very close to the equator, and then going north to Agra, magnetic latitude 17°.3′, we should find a plateau of constant or unchanging intensity, whereas if we went from Agra to Peshawar, only 7°.7′ north of Agra, we should find not a small, but a considerable, increase in the vertical incoming intensity due to the fact that somewhere within these 7°.7′ this annihilation band of silicon rays would be able to get down to earth.

We realized well that we were taking a wild chance in making an expensive trip to India to test that point, but if we could thus get a satisfactory test of the atom-annihilation hypothesis the chance would be worth the taking. We did little or no talking about what led us on this chase, but thought the experiments would be worth while even if they came out negatively, which we were quite prepared to expect they would. Our measurements actually yielded the predicted cosmic-ray plateau between Bangalore and Agra (17° north of the equator). Then going to Peshawar and repeating exactly the same kind of measurements, we found an increase in going these 7°.7′ farther north to be about 15 percent. This we interpreted as caused by the entrance between Agra and Peshawar of the looked-for silicon rays with some possible small ingredients

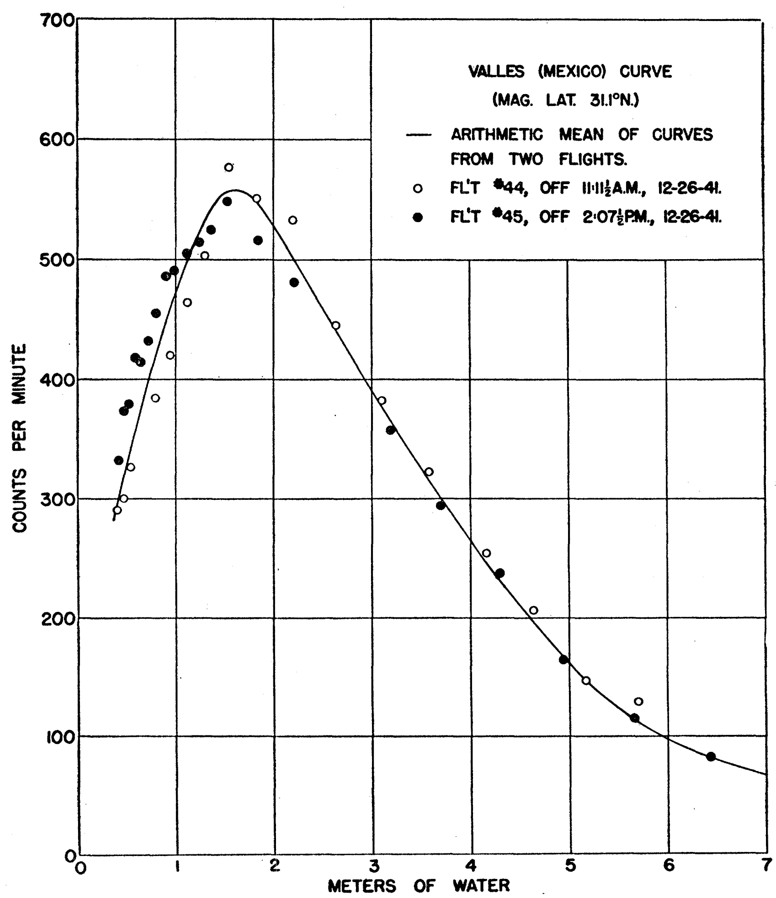

FIG. 10. The full curve is the arithmetic mean of the curves from the flights, two only, made at Valles, all observed points being recorded as in Fig. 9. *Maximum at 560 ions.*

from the nearby elements Mg, Al, P, and S. In other words, the theory seemed to have had an interesting success. (See Fig. 7.)

On the other hand, if we went through the same type of tests with electroscopes, instead of vertical counters, the theory as presented in the LeMaitre-Vallarta diagram indicated that the total intensity of the incoming rays should increase continuously between Bangalore and Agra. We repeated the same kind of experiments, then, with electroscopes in the place of counters and found these quite critical results agreeing with the theory, thus tending to show that our results were not due to any uncertainties in our measurements. (Figure 8.)

Another test of the theory was found in the fact that in our preceding experiments between the magnetic equator in Peru and the latitude of Panama, lying at 20° north magnetic, we had found both at sea level and, as shown in Fig. 1 and also in Fig. 2, at an altitude of 22,000 feet a plateau of unchanging cosmic-ray intensity. This seemed to prove the prediction that *vertical* silicon rays of intensity 13.2 billion electron volts could get in at the equator in Peru, in which case there should have been no further increase in going up to Panama at latitude 20°. In other words, there were no new incoming rays of any sort, even those entering at considerable angles from the vertical, between 0° and 20° in Peru, but there were such new incoming non-vertical silicon rays between 0° and 17° in India caught by electroscope receivers. (Figure 8.) In a word, the plateaus which we had found between Panama and Mollendo, both in

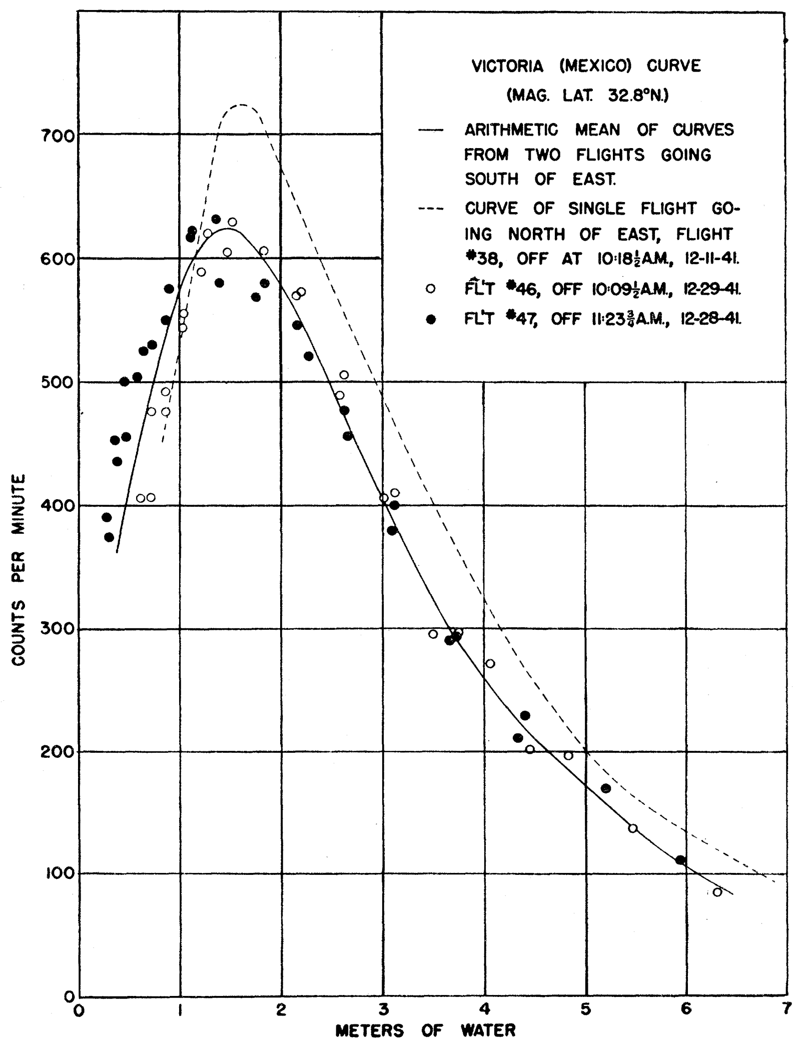

FIG. 11. The full curve is the mean of two flights at Victoria, when the balloons went south of east; the broken curve, the single flight in which the balloons went north of east. Therefore, the latitude of Victoria, Mag. 32°.8 N, is thought to be very close to the latitude of first entrance of the neon-oxygen-annihilation ray band. *Maximum at 625 ions.*

our sea-level experiments in '26 and later in our airplane experiments up to 22,000 feet in 1932, were in line with the atom-annihilation theory, and thus constituted evidence in its favor, especially since in India the same kind of experiments between the same latitudes, 0° to 20°, yielded different results as the theory suggested they should. Both of these two plateaus, the one at sea level and the one at 22,000 feet, constitute, then, quite cogent arguments for the atom-annihilation theory.

Our next job was to make similar flights in Mexico, where our hypothesis predicted that the silicon plateau for vertical rays ought to extend clear up into the middle of Mexico, so, in December '41, in spite of our responsibilities in the war, Neher, Pickering, and I rigged up in a truck a cosmic-ray laboratory and with new equipment made a series of four flights in Acapulco, magnetic latitude 25°.6, just above the magnetic lati-

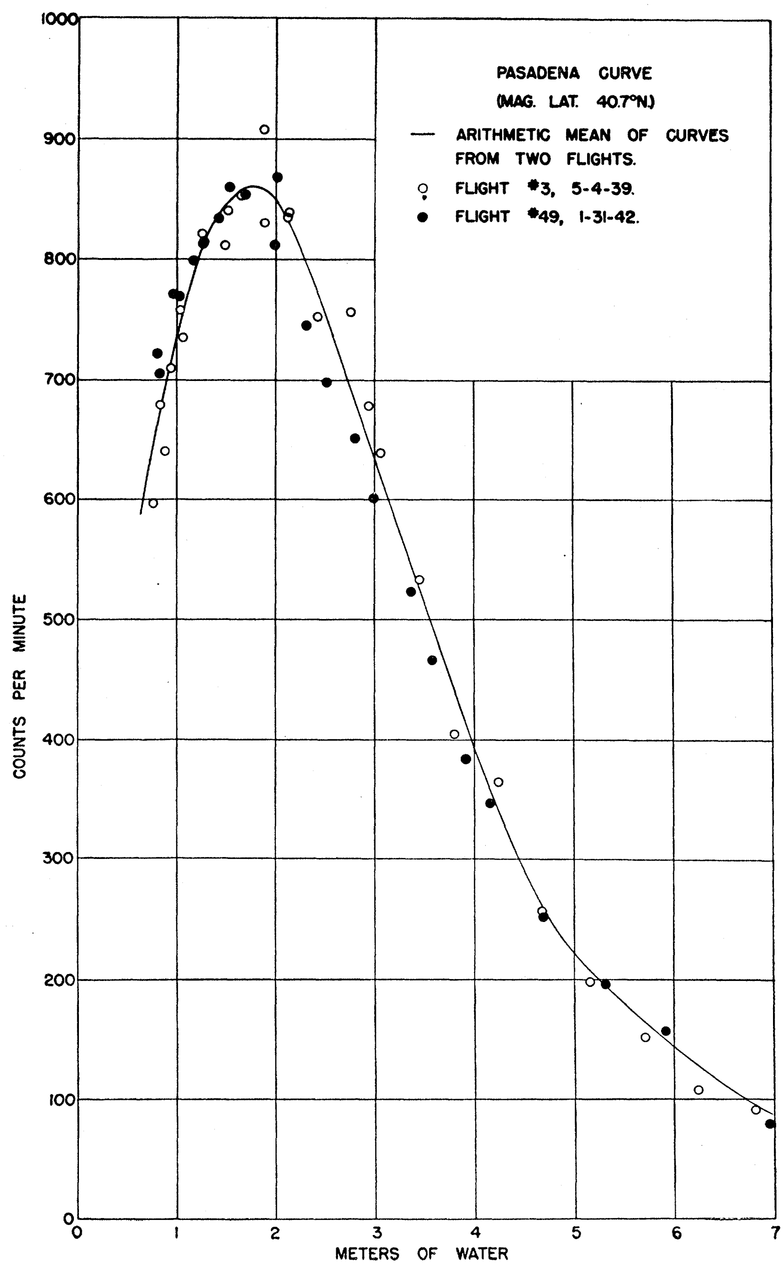

FIG. 12. At the latitude of Pasadena the annihilation rays of both oxygen and nitrogen appear to be able to get fully in vertically. *Maximum at 860 ions.*

tude of Peshawar. The best vertical counter flight made in Acapulco agreed, probably within the limits of the uncertainty of our available techniques, with the like flight made in Peshawar, as theoretically it should have done.

But the main interest in the flights in Mexico centered in the following points: When measuring with vertical counters the plateau of constant silicon, intensity ought to extend from the equator clear up to 32° or 33° in Mexico. Did it do so? We have already indicated that our earlier airplane flights, even with electroscopes, showed that it extended from the magnetic equator up to Panama, latitude 20°, and we had become so confident from our results in India that we predicted that in flights made with incoming vertical rays that plateau would extend from the magnetic equator clear up to about magnetic latitude 33°, where we figured that the oxygen-annihilation rays would just begin to be able to break vertically through the resistance of the earth's magnetic field. Was there, then, a flat plateau for vertical rays between Acapulco, at about latitude 25°.6, and Valles, at latitude 31°.1, nearly 400 miles further north? The measurements actually brought to light exactly the predicted plateau between these two points (see Figs. 9 and 10), while when we went only another 100 miles north to Victoria we found a sudden marked increase as predicted if the oxygen-annihilation rays could get in vertically at about the latitude of 33°. (See Figs. 10 and 11.) We made similar tests between Victoria and Pasadena in magnetic latitude 40°.5, or 540 miles nearer the magnetic pole, and found a large increase (some 38 percent) between these latitudes (see Figs. 11 and 12), as we already knew we had to find both from previous experimenting at sea level and from our theory, which indicated that between magnetic latitude 33 and 40.5 both oxygen and nitrogen annihilation rays should be added to the readings at Valles. These results obtained with airplane flights were also checked at sea level by vertical counter measurements, as shown by the readings of Table II.

In March '42, in spite of our absorption in war duties, Pickering and I succeeded in making two flights at St. George, Utah, 280 miles nearer the north magnetic pole than Pasadena, and found a considerable increase, which we attributed to the entrance between Pasadena and St. George of a new band of carbon atom-annihilation rays. Then we again drove north to Pocatello, Idaho, nearly 400 miles nearer the pole than St. George, and found a constant plateau between these two points (see Fig. 13), as we should since there is no new atom-annihilation radiation which can come in between that corresponding to carbon-annihilation rays and helium-annihilation rays, for there are no abundant atoms between these atomic weight limits. We were not altogether satisfied with these last results because we did not get in enough flights to obtain thoroughly reliable data at the last two latitudes.

No evidence has come in since then which is unfavorable to the theory, unless it be that which we ourselves obtained in August and September, 1947. The weakness of our technique for obtaining accurate vertical intensities consists in the fact that during the flight the vertical counters expose a larger opening to incoming rays when the counters are oriented, say, east and west than when they are oriented north and south. This may account for some of the fluctuations, or scatter, seen in our readings. These should not be serious because the average resulting from rota-

TABLE II. Summary of ground-level counts with standard counter set from Acapulco to Pasadena.

	Counts	Time in minutes	Rate per minute	Paulin bar. reading	Corrected rate*	Mean rate†	
Acapulco (mag. lat. 25.8°)	5004	208	24.0	29.91	24.9	90	90.5
Valles (mag. lat. 31.15°)	6005	246	24.4	29.92	25.3	91	
Victoria (mag. lat. 32.8°) Dec. 10	13585	504	27.0	29.03	25.9	94	94
Victoria (mag. lat. 32.8°) Dec. 28	8086	304	26.6	29.30	26.1	94	
Monterrey (mag. lat. 34.6°)	5797	197	29.5	28.42	26.5	96	95.5
Laredo (mag. lat. 36.65°)	16408	633	25.9	29.70	26.4	95	
San Antonio (mag. lat. 38.5°)	6747	239	28.2	29.25	27.6	100	98
Junction, Texas (mag. lat. 38.5°)	11171	370	30.2	28.17	26.6	96	
Pasadena (mag. lat. 40.7°)	29736	1073	27.7	29.50	27.7	100	100

* Corrected rates to Paulin barometer reading of 29.50. Correction 0.9 percent per 0.1″.
† The last column shows no change from Acapulco to Valles (5°.2 = 360 mi.), but a 3.5 increase to Victoria (1°.8 = 124 mi.), a further increase to Monterrey (1°.8 = 124 mi.), another increase to San Antonio (5°.8 = 400 mi.), and a final increase to Pasadena (2°.0 = 145 mi.)

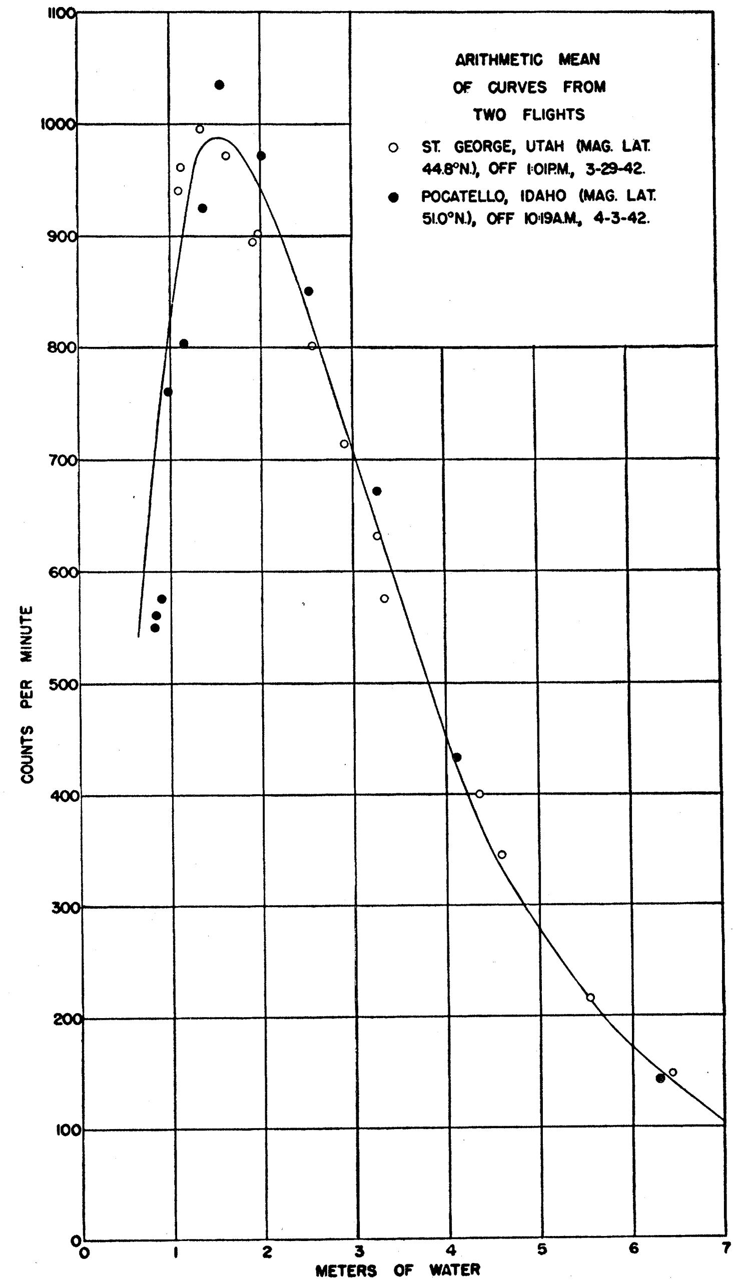

FIG. 13. Shows that there is practically no new energy entering vertically in the long latitude stretch between St. George and Pocatello, although there is clear evidence of the entrance of carbon-annihilation rays between Pasadena and St. George, Utah. *Note maximum at 980 ions.*

tion in flight probably offsets this disadvantage, but we think it desirable to repeat with Dr. Neher's new symmetrical vertical counters these experiments of last year and those made in '41 and '42 in Mexico and the United States. We plan to do this as soon as possible. Our readings taken in August and September, 1947, were disappointingly erratic, probably due to the fact that the enormous electromagnetic waves from unprecedented solar activity, which interfered seriously with radio reception in '47, also distorted the normal pattern of incoming rays always found earlier by ourselves in both 1936–7 and 1940. In a word, the irregularities due to this cause were great enough to mask the regularities which we were seeking to establish and improve. We hope we can eliminate in further work errors resulting from this cause.